DEPARTMENT OF DEFENCE

DEFENCE SCIENCE & TECHNOLOGY ORGANISATION

DSTO

Degradation of Peel and Tensile Strength of Bonded Panels Exposed to High Humidity

Andrew N. Rider

DSTO-TR-1272

Degradation of Peel and Tensile Strength of Bonded Panels Exposed to High Humidity

Andrew N. Rider

Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

DSTO-TR-1272

ABSTRACT

Bonded sandwich panel structural integrity is an important component in the successful maintenance and continued operation of RAAF F-111 aircraft through to the planned withdrawal date of 2020. F-111 airframe stiffness and strength is dependent on the integrity of bonded sandwich panel structure. Currently, limited knowledge exists as to the effect of environmental exposure on the mechanical integrity of bonded sandwich panels. The work presented in this report summarises honeycomb studies undertaken in AIR task 98/186 that were designed to examine the influence that environmental exposure would have on the peel and tensile strength of bonded sandwich honeycomb panels constructed from either original materials or materials used in the refurbishment of damaged panels. The results indicate that the materials and processes used by the United States Airforce in repair and rebuild programs are susceptible to mechanical degradation as a result of exposure to high humidity conditions. However, the panels constructed during the original aircraft manufacturing indicate better resistance to the effects of environmental exposure.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

Published by

DSTO Aeronautical and Maritime Research Laboratory
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-012-149
November 2001

APPROVED FOR PUBLIC RELEASE

Degradation of Peel and Tensile Strength of Bonded Panels Exposed to High Humidity

Executive Summary

Bonded sandwich panel structural integrity is an important component in the successful maintenance and continued operation of Royal Australian Air Force (RAAF) F-111 aircraft through to the projected withdrawal date of 2020. F-111 airframe stiffness and strength is dependent on the integrity of bonded sandwich panel structure. Currently, limited knowledge exists as to the effect of environmental exposure on the mechanical integrity of bonded sandwich panels. Several examples of inflight loss of sandwich panels and panel skins have been reported together with ongoing repairs of honeycomb structure being undertaken at RAAF Amberley. This indicates that bonded panels have the potential to limit the available F-111 flying hours in the future and increase the financial burden of aircraft maintenance.

The work presented in this report summarises honeycomb studies undertaken in AIR task 98/186 that were designed to examine the influence that environmental exposure may have on the peel and tensile strength of bonded sandwich honeycomb panels constructed from either original materials or materials used in the refurbishment of damaged panels. The work detailed in this report can also assist with the bonded panel inspections being carried out in the F-111 Fuselage Teardown program, a large AMRL task supporting F-111 operation and maintenance. Failure modes and strength reduction observed in the Teardown inspection can be referenced to the data in this report to provide a more reliable estimate of the mechanical state of the bonded panels on the Teardown article. Information contributing to a knowledge of the mechanical state of bonded panels on F-111 aircraft and factors leading to bonded panel degradation can be used to develop better strategies for maintenance and repair, thereby reducing ownership costs and increasing the available flight hours for RAAF.

The peel and tensile strength of honeycomb sandwich panels constructed from selected materials used by the United States Air Force (USAF) were very susceptible to degradation after exposure to high levels of humidity. Tensile strength reduced between 50% and 70% and was accompanied by large increases in adhesion failure at the honeycomb core and adhesive interface. Samples tested in peel all indicated rapid onset of adhesion failure after humid exposure. These results suggested that honeycomb panels constructed from the materials examined in this report would exhibit significant reduction in mechanical strength if moisture was able to ingress into the interior of the bonded panel structure. After analysis of two sections of panels from a retired Horizontal Stabiliser, it was concluded that corrosion resulting from moisture ingress could lead to a significant reduction in panel strength. It is suggested that for inspections of panels on F-111 aircraft it is important to carefully examine regions that are susceptible to moisture ingress, such as fastener holes or edgemembers. The poor durability of adhesive bonds on F-111 aircraft highlight the importance of effective sealing of panels to prevent moisture ingress.

It is expected that results from this study can assist with bonded panel inspections on the F-111 teardown article as well as developing strategies to assist in more effective inspection and maintenance of bonded panels.

Author

Andrew Rider
Airframes and Engines Division

Andrew Rider joined Airframes and Engines Division at DSTO in 1988 as a Professional Officer Class 1. He has a Bachelor of Applied Science in Chemistry from Swinburne University of Technology and a PhD in Physical Chemistry from the University of New South Wales. He is currently employed as a Research Scientist and works within Airframes and Engines Division. He is involved in research to understand degradation mechanisms involved in bonded structure and repairs used on F-111 and F/A-18 fighter aircraft.

Contents

1. Introduction

Bonded sandwich panel structural integrity is an important component in the successful maintenance and continued operation of RAAF F-111 aircraft through to the projected withdrawal date of 2020. F-111 airframe stiffness and strength is dependent on the integrity of bonded sandwich panel structure. Currently, limited knowledge exists as to the effect of environmental exposure on the mechanical integrity of bonded sandwich panels. Several examples of inflight loss of sandwich panels and panel skins have been reported together with ongoing repairs of honeycomb structure being undertaken at RAAF Amberley [1]. This indicates that bonded panels have the potential to limit the available F-111 flying hours in the future and increase the financial burden of aircraft maintenance.

The work presented in this report summarises honeycomb studies undertaken in AIR task 98/186 that were designed to examine the influence that environmental exposure may have on the peel and tensile strength of bonded sandwich honeycomb panels constructed from either original materials or materials used in the refurbishment of damaged panels. Information derived from these studies will provide important support for task AIR 00/140, the F-111 Fuselage Teardown program. In the Teardown program, bonded panels from an F-111 fuselage are being inspected to determine their structural condition. The work in this report should provide important reference information for the panel inspections by indicating the strength values of panels in the undegraded or degraded state as well as the potential failure modes that would be expected for peel and tensile failure modes. The results should also provide an indication of the effect that environmental exposure could potentially have on panel strength.

2. Experimental

2.1 Honeycomb Sandwich Fabrication

Honeycomb core from Alcore was degreased in trichloroethylene (TCE) prior to all bonding operations. The two types of honeycomb used are detailed in Table 1, along with the adhesives. Alcore Dura-Core honeycomb, JD Lincoln L-303, 3M AF-130-2 and 3M AF131-2 adhesives were materials used by the United States Air Force (USAF) for bonded repairs and panel rebuilds. RAAF have previously used AF-130-2 and 3M AF131-2 adhesives for bonded repairs and now use FM-300 and AF-131-2. AF131-2 contains Kevlar filler and is used for high temperature applications. The effects of moisture exposure on the mechanical properties of FM-300 have been examined and will be reported in a separate publication[2]. Untreated honeycomb was used for construction of the original panels. Aluminium Skin material received a chromic acid etch (CAE) to simulate the pre-treatment procedure used in the original construction and rebuild process[1]. The CAE involved immersing aluminium 15 minutes in the 65^{0}C CAE solution, followed by tap and de-ionised water rinsing. The CAE solution

had the following composition (g/L): $Na_2Cr_2O_7.2H2O$ (60), H_2SO_4 (318), Al-2024 T3 aluminium (1.3), de-ionised water (balance) [3].

Table 1 Materials used for sandwich panel fabrication

Material	Details
Alcore 5056 Untreated Honeycomb	Cell size 3/16", thickness 5/8", foil gauge 0.002", node adhesive: polyamide. 5056 Aluminium alloy. Manufactured by Alcore.
Alcore Dura-Core Honeycomb	Cell size 3/16", thickness 5/8", foil gauge 0.002", node adhesive: polyamide. 5056 Aluminium alloy. Foil has protective chromium based coating. Manufactured by Alcore.
JD Lincoln L-303	High peel strength, flame retardant, modified epoxy, cured at 120^0C, 25-50 psi, 60 minutes. Tensile strength*: 1150psi at 25^0C. Peel Strength* : 6.3 mm.kg/mm at 25^0C.
AF130-2	Modified epoxy film adhesive, cured at 177^0C and 50 psi, 60 minutes. Tensile strength*: 1210psi at 25^0C.
AF131-2	High temperature epoxy adhesive with Kevlar filler. Modified epoxy film adhesive, cured at 177^0C and 50 psi, 60 minutes. Tensile strength*: 1130psi at 25^0C.

* Strength values quoted by manufacturer

2.2 Sandwich Panel Conditioning and Testing

Sandwich panels were constructed from Alcore-Duracore honeycomb and JD Lincoln L-303 adhesive, Alcore untreated honeycomb and AF-130-2 adhesive and Alcore untreated honeycomb and AF-131-2 adhesive. The panels all had only one skin bonded with the structural adhesives listed in Table 1, prior to exposure to a 70^0C condensing humidity environment. Panels were removed after 7, 14, 30, 90 and 150 days. A second skin was bonded to the conditioned sandwich panel after conditioning using EA9309.3NA paste adhesive, which was cured at room temperature overnight. This process insured that moisture had direct access to the fillet bonds and was intended to simulate conditions in which moisture had migrated into the panel. The experiment would then provide an estimate of the potential reduction in strength that could occur in panels that contained moisture and the time for the degradation to occur.

Once the panels were conditioned, the tensile and peel strength was assessed using a portable adhesion tester and the climbing drum peel method. The portable adhesion test method is based on ASTM D 4541-95 [4]. The test method involved bonding a 1" diameter stub to the outer skin of the honeycomb sandwich panel with EA9309.3NA paste adhesive after pre-treating both skin and stub surfaces with a grit-blast and silane treatment. After allowing the adhesive to cure, a ring was cut out from the skin around the outer perimeter of the stub. Pressure applied to the piston, which reacted against a

disk placed over the stub, detached the skin from the honeycomb at a pressure equivalent to the load measured in flat-wise tension testing. Pressure applied to the piston insured 100psi was reached in 40 seconds, as specified in ASTM D 4541-95 [4]. Tests were conducted at room temperature. ASTM D 1781-98 [5] climbing drum peel test was employed to assess the peel resistance of adhesive bonds formed between the aluminium skin and honeycomb core material. Specimens had dimensions of 76mm x 305mm including the skin overlap for machine gripping. Average peel load values were used to determine the peel torque, T (mm.kg/mm), as specified in the standard. Specimens were tested at room temperature with a cross-head displacement of 25mm/min.

2.3 Examination of Retired F-111 Panels from Amberley Airbase

Two retired bonded panels from Amberley Airbase that contained damaged regions outside the allowable areas permitted in the Structural Repair Manual were also examined using the Portable Adhesion Tester, described in section 2.2. The first component examined was the tip of a horizontal stabiliser (Stab-Tip) that contained a large corrosion area near in the corner of the sample. This article was tested in the as received state and then was immersed in a 50^{0}C water bath for 13 months. Tensile strength measurements taken at 20 days and 13 months immersion assessed the effect of moisture in the degradation of the panel mechanical strength.

The second component examined was an F-111 Starboard Horizontal Stabilizer Tip Cap (Stab-Tip Cap). This component was previously inspected using a range of NDI methods to determine the presence of panel damage or degradation beneath the panel skin [6]. Four areas from these inspections were examined to assess the effect of panel degradation on tensile strength from practical bonded panel specimens.

3. Results

3.1 Influence of Moisture on Panel Tensile and Peel Strength

Figure 1 and Figure 2 indicate the change in Tensile and Peel strength of the bonded panels exposed to a 70^{0}C and condensing humidity environment. The tensile strength of all the samples reduces by 400-600psi over a 150 day period. The JD Lincoln and Duracore sample tensile strength degreases gradually over the first 30 days, whereas the untreated honeycomb and AF130-2 and AF131-2 samples both degrade very rapidly in the first 7 days. The peel strength of the JD Lincoln/Duracore sample shows a more rapid decrease than the tensile strength, although the overall reduction does not appear to be as great as the tensile strength reduction. The change in peel strength of untreated honeycomb and AF130-2 and AF131-2 samples is not as marked. Both these adhesives are very brittle and their peel strengths are very low in the control samples. The major information to be established for the exposure of the AF130-2 and AF131-2 samples is the change in failure modes resulting from humid exposure.

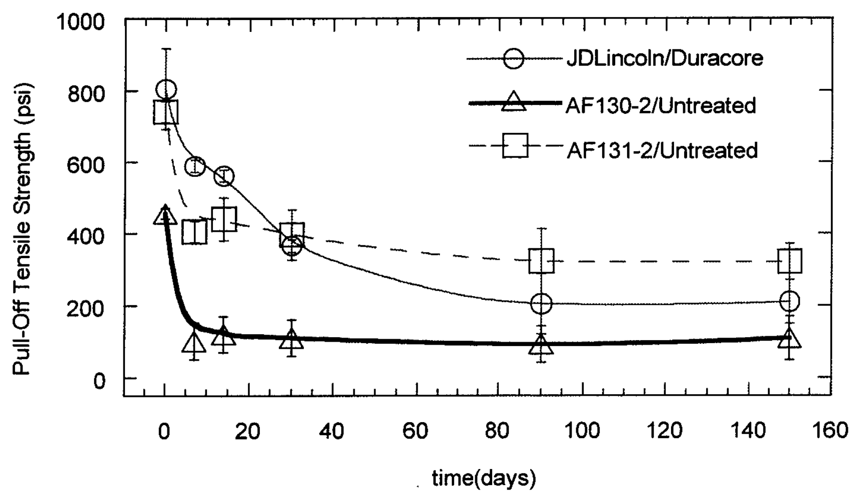

Figure 1 *Honeycomb panel tensile strength as a function of exposure to a 70^{0}C/100% R.H. environment.*

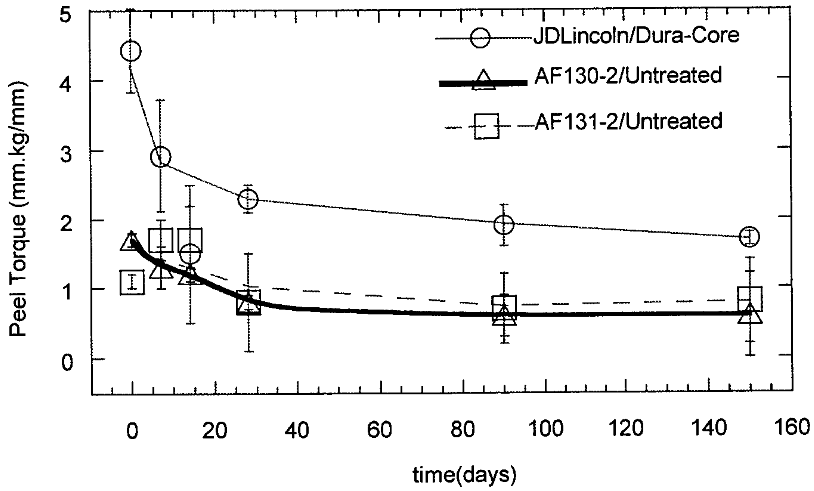

Figure 2 *Honeycomb panel peel strength as a function of exposure to a $70^0C/100\%R.H.$ environment.*

Figure 3 to Figure 11 indicate the failure surfaces resulting from the tensile test measurements of the conditioned honeycomb samples. The JD Lincoln/Duracore and untreated honeycomb/AF130-2 samples both indicate that after 30 days of exposure there is almost 100% adhesion failure resulting from pull-out of the fillet bonds from the honeycomb core material i.e. fillet bond pull-out. In contrast to these samples, the untreated honeycomb/ AF131-2 sample indicates a percentage of cohesive failure of the fillet bond and fillet bond pull-out for all the conditioned samples.

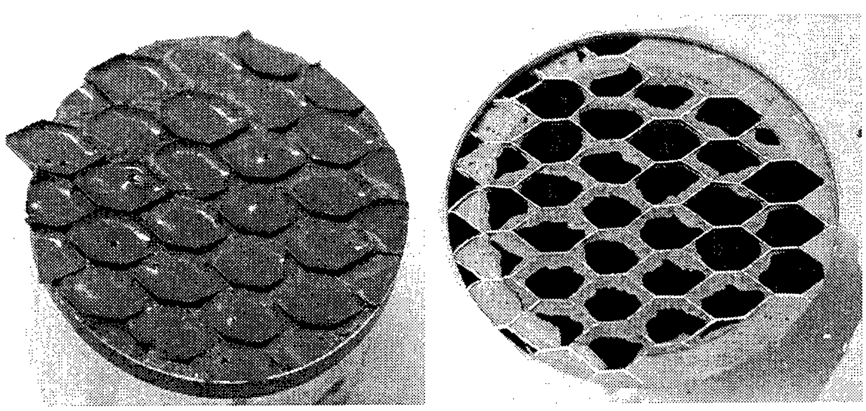

Figure 3 *Failure surfaces resulting from tensile testing of the Dura-Core honeycomb and JD Lincoln adhesive control specimen, indicating a mixture of cohesive failure and fillet bond pull-out.*

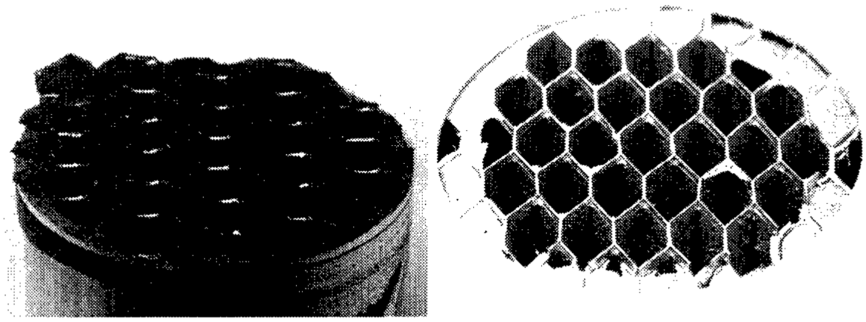

Figure 4 *Failure surfaces resulting from tensile testing of the Dura-Core honeycomb and JD Lincoln adhesive conditioned 30 days at 70^0C/100%R.H., indicating fillet bond pull-out.*

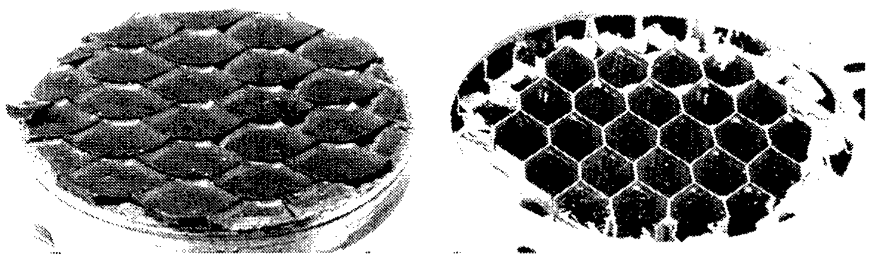

Figure 5 *Failure surfaces resulting from tensile testing of the Dura-Core honeycomb and JD Lincoln adhesive conditioned 150 days at 70^0C/100%R.H., indicating fillet bond pull-out.*

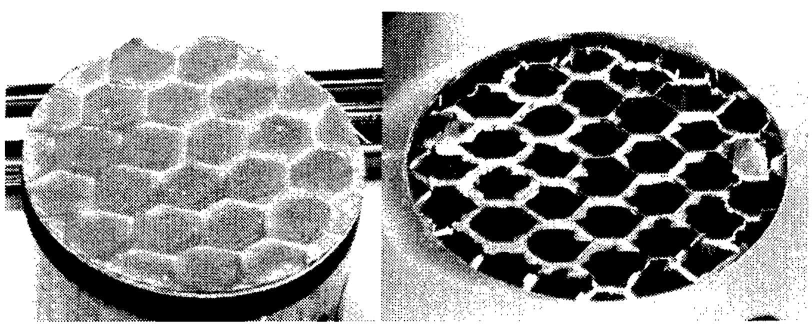

Figure 6 *Failure surfaces resulting from tensile testing of the Untreated honeycomb and AF130-2 adhesive control specimen, indicating a mixture of cohesive failure and fillet bond pull-out.*

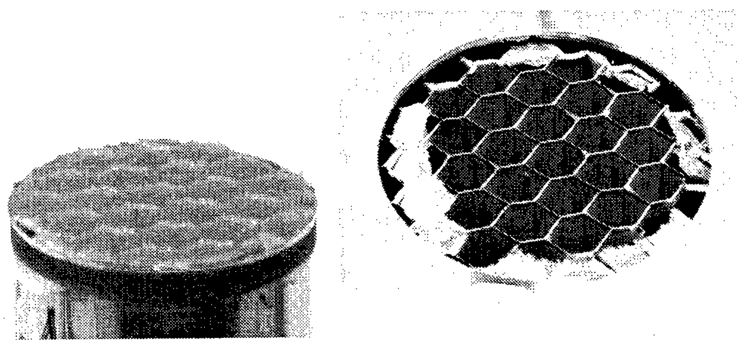

Figure 7 *Failure surfaces resulting from tensile testing of the Untreated honeycomb and AF130-2 adhesive conditioned 30 days at 70^0C/100%R.H., indicating fillet bond pull-out.*

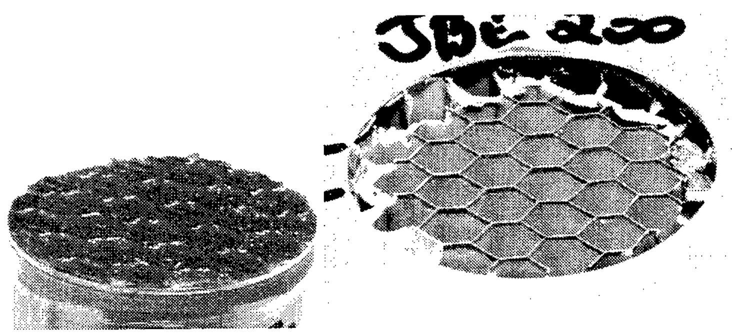

Figure 8 *Failure surfaces resulting from tensile testing of the Untreated honeycomb and AF130-2 adhesive conditioned 150 days at 70^0C/100%R.H., indicating fillet bond pull-out.*

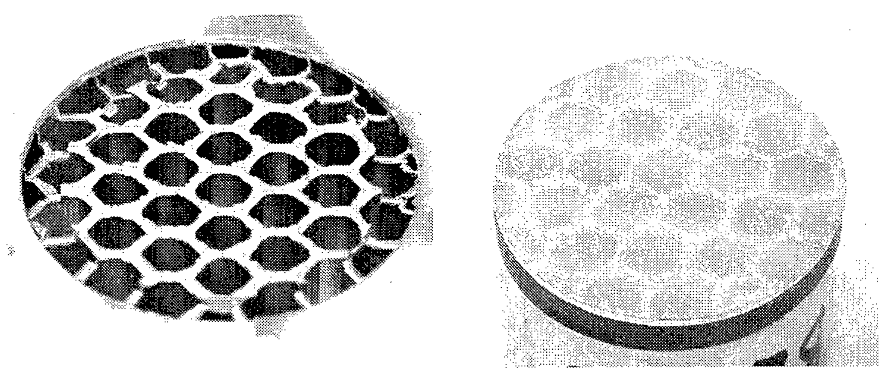

Figure 9 *Failure surfaces resulting from tensile testing of the Untreated honeycomb and AF131-2 adhesive control specimen, indicating cohesive fillet bond failure.*

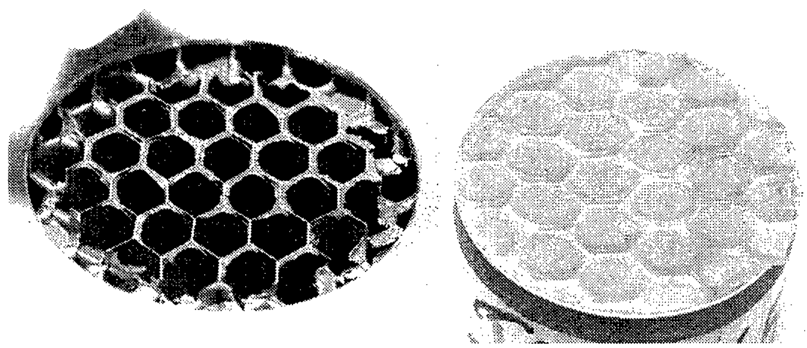

Figure 10 *Failure surfaces resulting from tensile testing of the Untreated honeycomb and AF131-2 adhesive conditioned 30 days at 70^{0}C/100%R.H., indicating fillet bond pull-out and cohesion failure.*

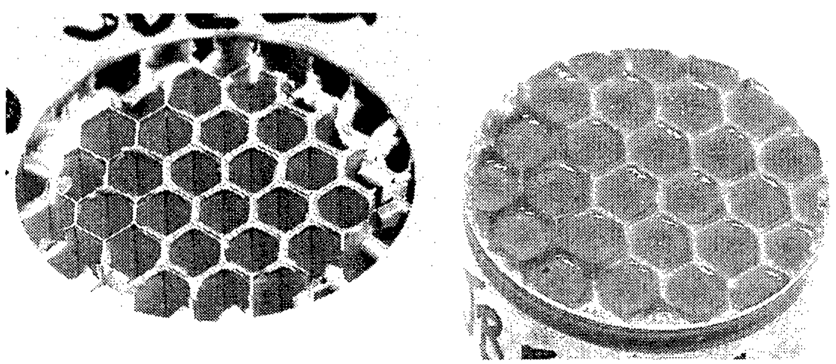

Figure 11 *Failure surfaces resulting from tensile testing of the Untreated honeycomb and AF131-2 adhesive conditioned 150 days at 70^{0}C/100%R.H., indicating fillet bond pull-out and cohesion failure.*

Figure 12 to Figure 20 indicate the failure surfaces resulting from the peel test measurements of the conditioned honeycomb samples. Examination of the JD Lincoln/Duracore control sample indicates that there is a significant percentage of adhesion failure between the skin and adhesive. This suggests that the CAE pretreatment of the aluminium skin, used in typical panel rebuilds by the USAF does not provide a good quality bond. Upon exposure to the humid environment the JD Lincoln/Duracore samples all indicate a mixture of fillet bond pull-out or adhesion failure between the skin and adhesive. In contrast to the control sample, the adhesion failure between the skin and adhesive is almost 100%, whereas in the control sample it is between 20-40%. The mixture of failure modes for the conditioned JD Lincoln/Duracore samples indicates that both interfaces are equally weak when loaded in peel and may fail at either interface. Very similar behaviour is also observed for the conditioned untreated honeycomb/ AF130-2 samples. Adhesion failure increases to 100% after humid exposure and failure may occur at the adhesive to skin or adhesive to honeycomb interface. In contrast to the AF-130-2 and JD Lincoln samples, the conditioned AF131-2 samples all indicate a mixture of cohesive failure as well as failure at the adhesive to skin or adhesive to honeycomb interface, with the adhesion failure modes increasing with exposure time. The AF131-2 also shows different failure modes to the two other systems when tested in tension.

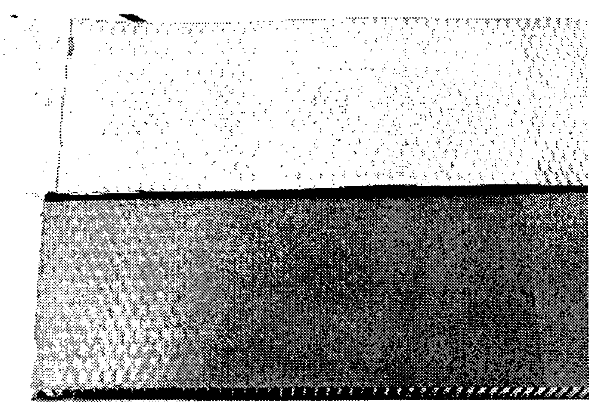

Figure 12 *Failure surfaces resulting from peel testing of the Dura-Core honeycomb and JD Lincoln adhesive control specimen, indicating a mixture of cohesive failure and skin to adhesive failure.*

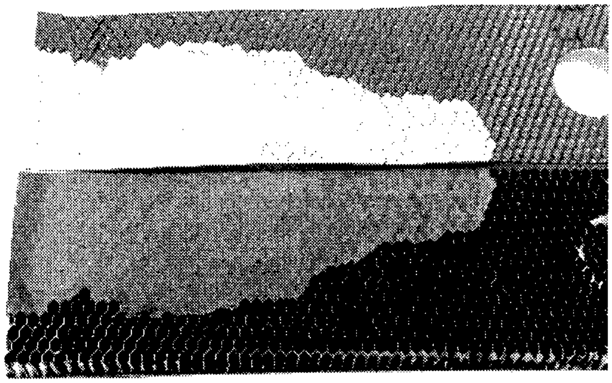

Figure 13 *Failure surfaces resulting from peel testing of the Dura-Core honeycomb and JD Lincoln adhesive conditioned 30 days at 70^0C/100%R.H., indicating fillet bond pull-out and skin to adhesive failure.*

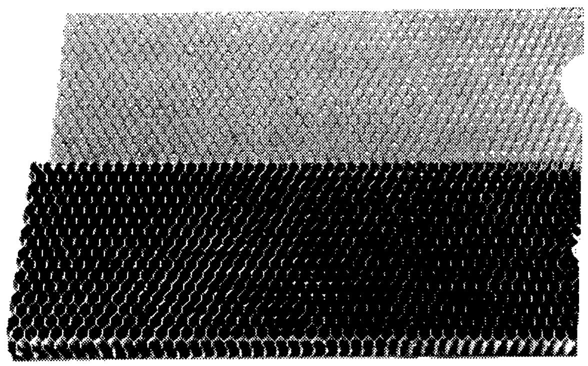

Figure 14 *Failure surfaces resulting from peel testing of the Dura-Core honeycomb and JD Lincoln adhesive conditioned 150 days at 70^0C/100%R.H., indicating fillet bond pull-out.*

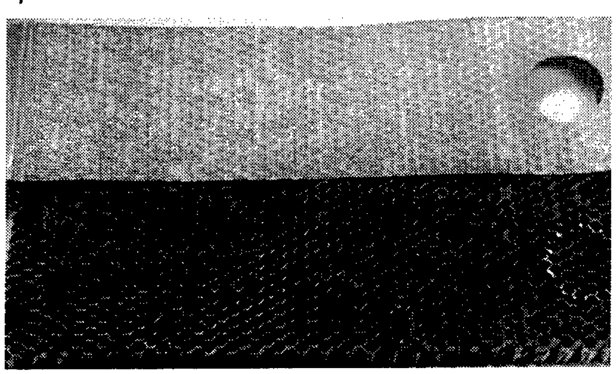

Figure 15 *Failure surfaces resulting from peel testing of Untreated honeycomb and AF130-2 adhesive control specimen, indicating a mixture of cohesive failure and skin to adhesive failure.*

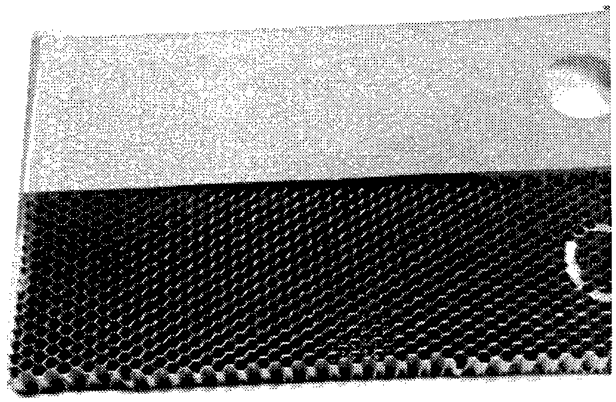

Figure 16 *Failure surfaces resulting from peel testing of the Untreated honeycomb and AF130-2 adhesive conditioned 30 days at 70^0C/100%R.H., indicating fillet bond pull-out.*

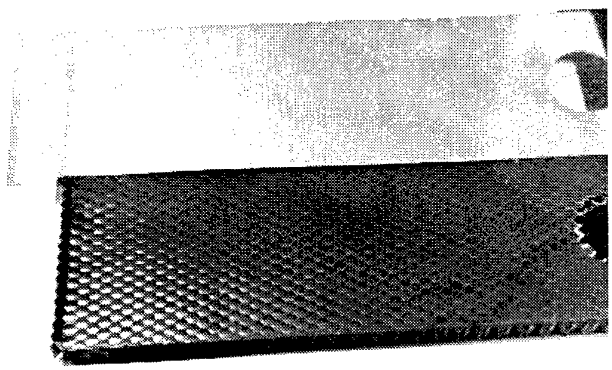

Figure 17 *Failure surfaces resulting from peel testing of the Untreated honeycomb and AF130-2 adhesive conditioned 150 days at 70^0C/100%R.H., indicating skin to adhesive disbond.*

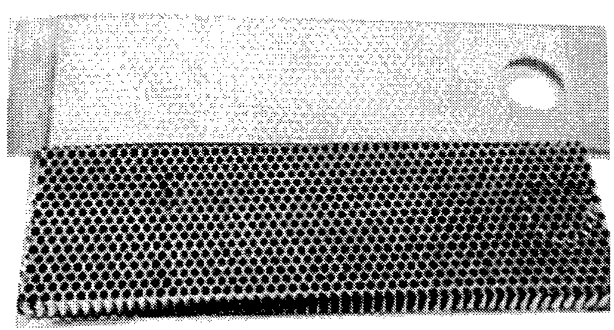

Figure 18 *Failure surfaces resulting from peel testing of Untreated honeycomb and AF131-2 adhesive control specimen, indicating a mixture of cohesive failure and skin to adhesive failure.*

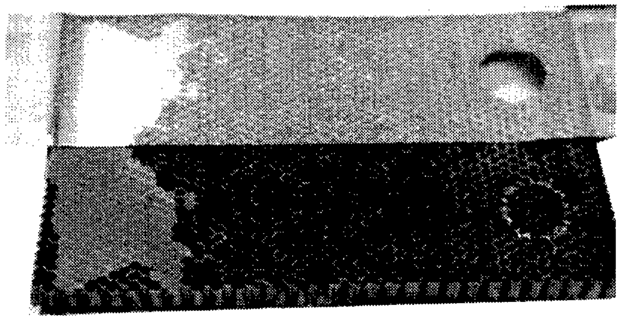

Figure 19 *Failure surfaces resulting from peel testing of the Untreated honeycomb and AF131-2 adhesive conditioned 30 days at 70^0C/100%R.H., indicating fillet bond pull-out, cohesion failure and skin adhesive disbond.*

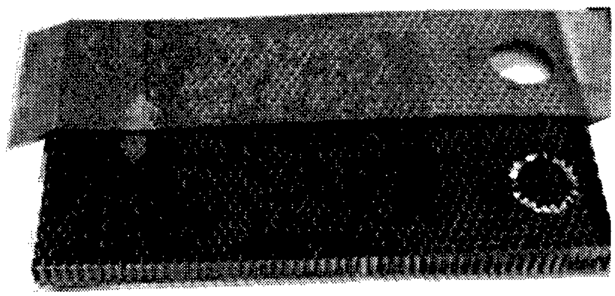

Figure 20 *Failure surfaces resulting from peel testing of the Untreated honeycomb and AF131-2 adhesive conditioned 150 days at 70^0C/100%R.H., indicating fillet bond pull-out and cohesion failure.*

Figure 21 and Figure 22 indicate the measured tensile and peel strength as a function of adhesion failure for the three different honeycomb/adhesive systems. The results suggest that there is an inverse linear relationship between the mechanical strength and the percentage of adhesion failure. Surprisingly, both figures indicate that residual strength remains even when there is 100% adhesion failure. This result may suggest that the mode of failure is caused by moisture diffusion between the adhesive and metal surface of the core or skin material displacing adhesive bonds. The residual strength may indicate that there are still some adhesive bonds that are not disrupted by the interfacial water.

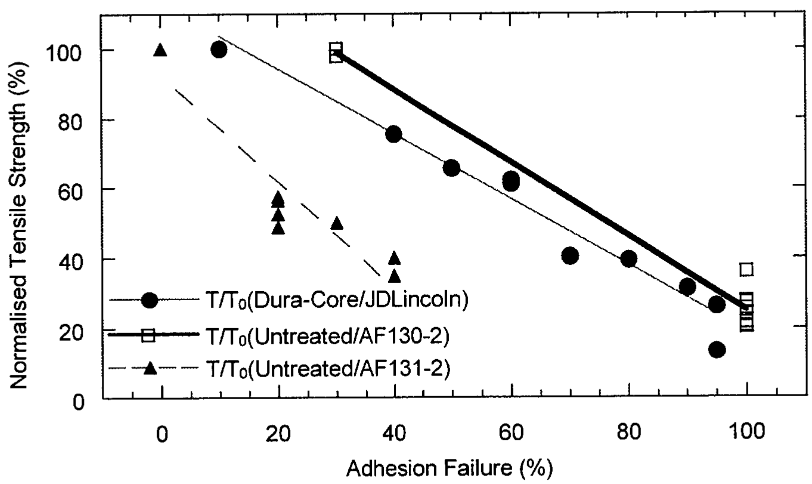

Figure 21 *Normalised tensile strength as a function of adhesion failure*

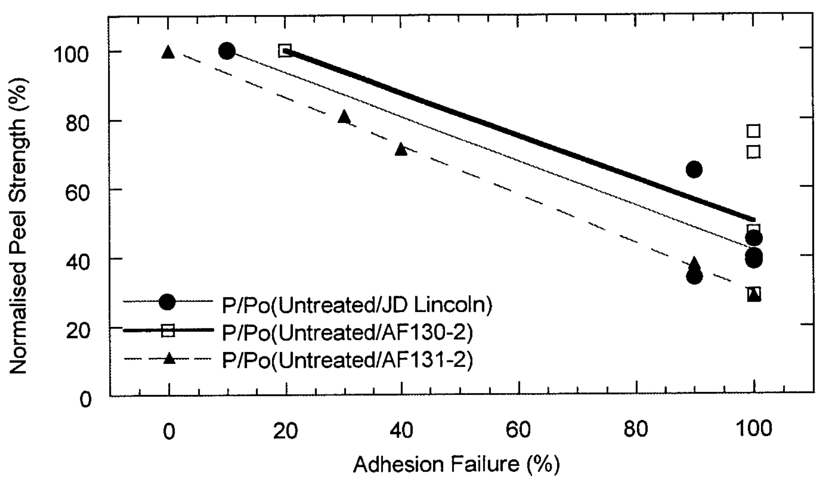

Figure 22 *Normalised peel strength as a function of adhesion failure*

3.2 The Effect of Moisture on the Tensile Strength of the Rejected Horizontal Stabiliser Tip (Stab-Tip)

Figure 23 indicates the locations of tensile strength measurements taken on a retired Horizontal Stabiliser Tip (Stab-Tip) from Amberley Air Base. The values for the tensile strength measurements acquired using the portable adhesion tester, refer section 2.2, are provided in Table 2. The average tensile strength value is 590 psi with a standard deviation of 100psi. All the samples either failed as a result of core fracture or cohesive fillet bond failure or a combination of both of these failure modes. The honeycomb had a cell size was 0.25" and the foil gauge was 3.4pcf. Typically, the core fracture is seen for honeycomb with these dimensions and the values around 600psi are acceptable values for undegraded honeycomb structure

Table 2 also indicates tensile values for samples taken from the Stab-Tip after 20 days and 13 months of immersion in 50^0C water. The location of the tensile test measurements are provided in Figure 24 to Figure 26. The data suggests that after 20 days little effect in bond strength results, although a low value of 320psi was recorded for a cohesive failure of the fillet bond adhesive. A similar value and failure mode was observed for a test taken after the Stab-Tip was immersed for 13 months in the 50^0C water. It is not clear whether this strength reduction is due to adhesive degradation or not. After 13 months of immersion the Stab-Tip indicated two samples with low values between 200-300psi that failed as a result of core corrosion. Two samples that indicated the onset of fillet bond pull-out did not indicate significant decreases in bond strength. This data suggests that an important factor that may lead to degradation of panel mechanical properties will be due to core corrosion. There is also some suggestion that fillet bond pull-out may occur for extended exposure of bonded panels to humid conditions. Failure surface images of core fracture, core corrosion and fillet bond pull-out are shown in Figure 27 to Figure 29. Generally, the results from the Stab-Tip immersion experiments suggest that in cases of well sealed panels, moisture diffusion into the panel is very slow.

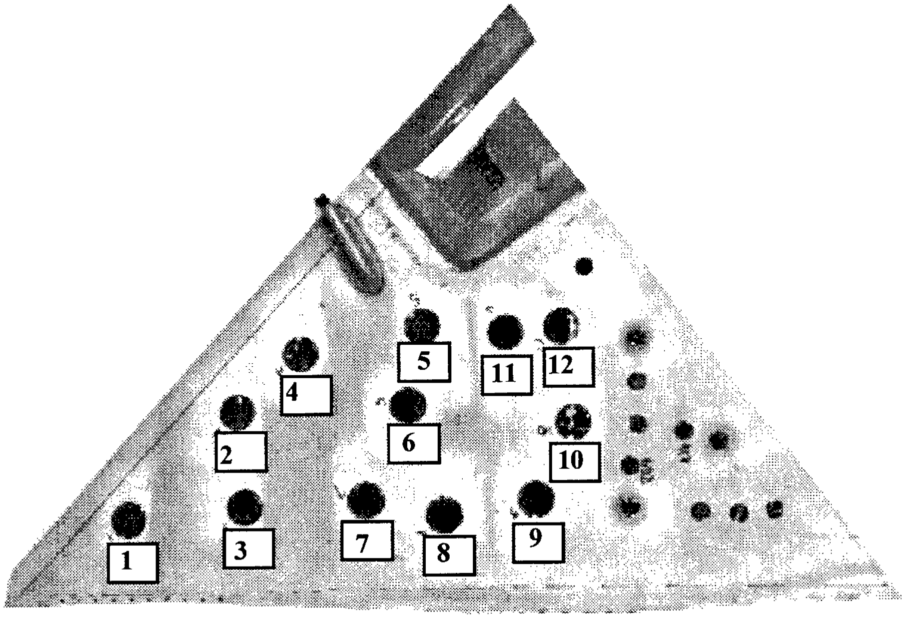

Figure 23 *Locations of tensile test measurements taken from the Stab-Tip, prior to conditioning.*

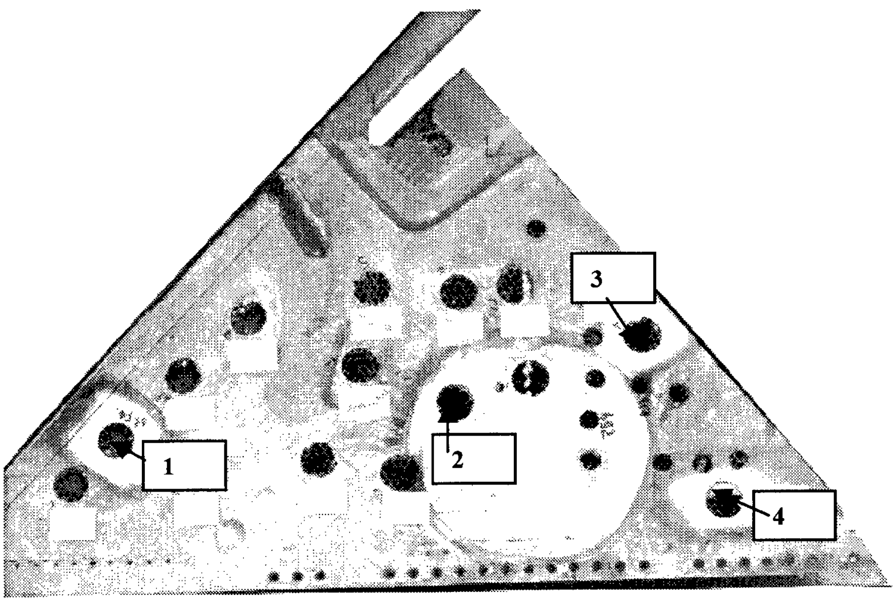

Figure 24 *Locations of tensile Test measurements taken from the Stab-Tip after conditioning in 50^{0}C ionised water for 20 days.*

Table 2 *Tensile strength of locations tested on the Stab-Tip before and after conditioning in 50^{0}C ionised water.*

Conditioning	Position of Tensile Test	Pull-Off Tensile Strength (psi)	Failure Mode
As received from Amberley Airbase after component retired	1	427	Core fracture/cohesive
	2	447	Core fracture/cohesive
	3	589	Core fracture/cohesive
	4	407	Core fracture/cohesive
	5	692	Cohesive
	6	630	Core fracture/cohesive
	7	671	Core fracture/cohesive
	8	712	Core fracture/cohesive
	9	651	Core fracture/cohesive
	10	529	Core fracture
	11	590	Core fracture
	12	712	Core fracture
Conditioned for 20 days in 50^{0}C water	1	321	Cohesive-failed opposite side to stub-skin bond
	2	666	Core fracture
	3	627	Core fracture/cohesive
	4	621	Core fracture/cohesive
Conditioned for 13 months in 50^{0}C water-side 1	1	219	Core corrosion
	2	280	Core fracture/cohesive-failed opposite side
	3	473	Core fracture
	4	482	Cohesive
	5	421	Cohesive/Pull-out
	6	773	Cohesive(foaming)
Conditioned for 13 months in 50^{0}C water-side 2	7	300	Core fracture/Core Corrosion
	8	514	Core fracture/cohesive
	9	594	Cohesive(foaming)
	10	681	Core fracture/cohesive
	11	414	Core fracture/cohesive-failed opposite side
	12	555	Cohesive/Pull-out
	13	563	Cohesive/Pull-out
	14	185	Core Corrosion

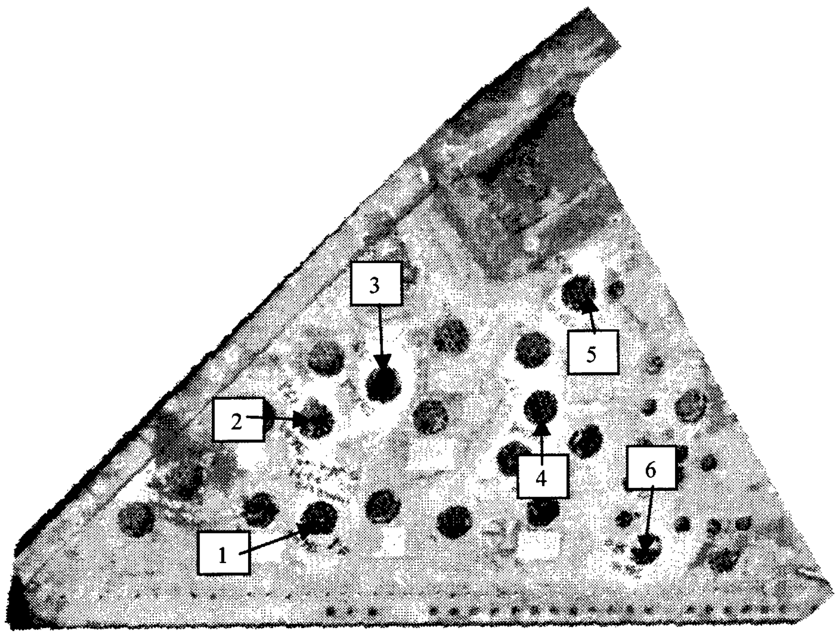

Figure 25 *Locations of tensile test measurements taken from side 1 of the Stab-Tip after conditioning for 13 months in* 50^0*C ionised water.*

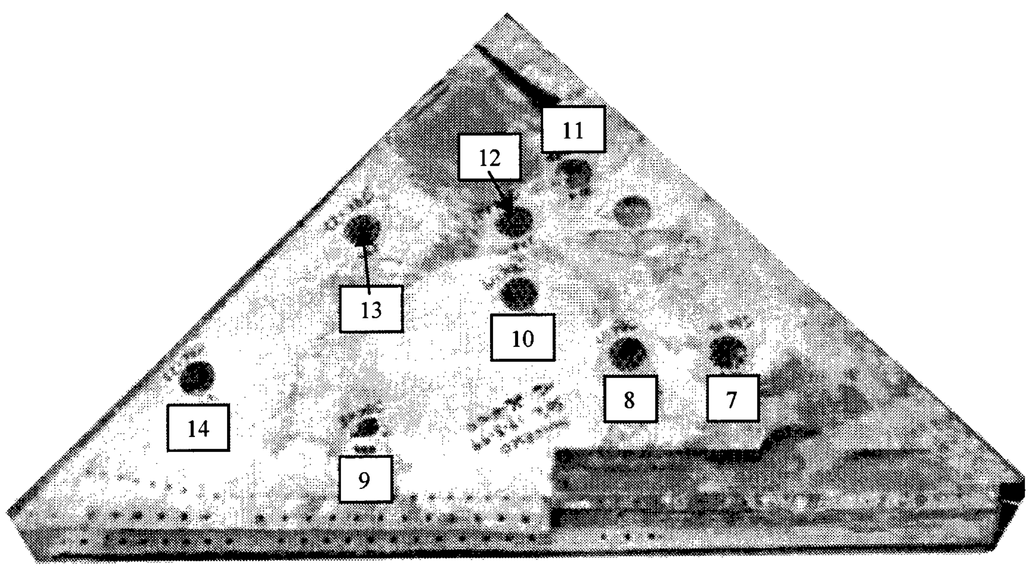

Figure 26 *Locations of tensile test measurements taken from side 2 of the Stab-Tip after conditioning for 13 months in* 50^0*C ionised water.*

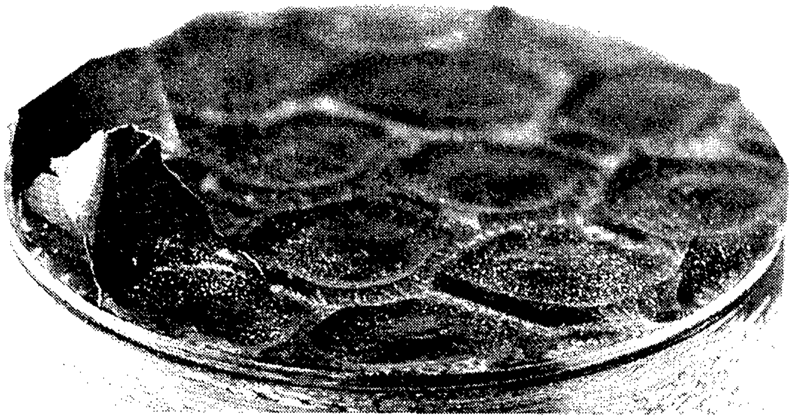

Figure 27 *Failure surface of the portable adhesion test stub taken from the Stab-Tip after immersion in 50^{0}C ionised water for 13 months, indicating regions of fillet bond pull-out.*

Figure 28 *Failure surface of the portable adhesion test stub taken from the Stab-Tip after immersion in 50^{0}C ionised water for 13 months, indicating regions of core corrosion leading to core fracture.*

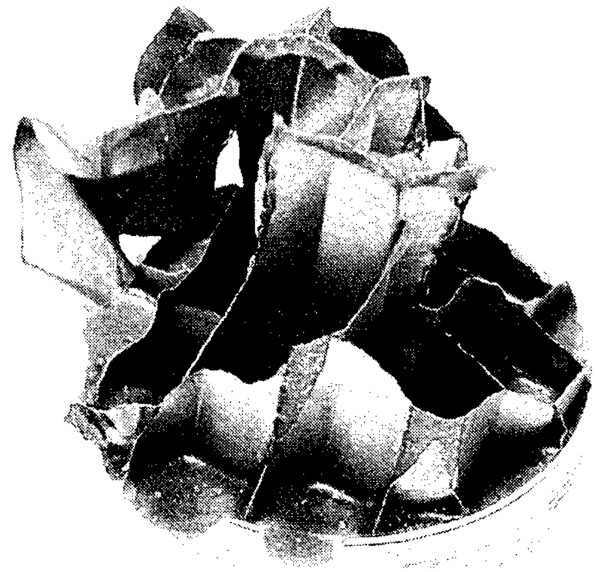

Figure 29 *Failure surface of the portable adhesion test stub taken from the Stab-Tip prior to immersion in 50^{0}C ionised water, indicating regions of honeycomb core fracture.*

3.3 The Effect of Moisture on the Tensile Strength of the Starboard Horizontal Stabilizer Tip Cap (Stab-Tip Cap)

Table 3 indicates the tensile strength of a number of locations on the Starboard Horizontal Stabilizer Tip Cap (Stab-Tip Cap), refer to Figure 30. Two regions that had NDI indications showed notable decrease in tensile strength. In one area a large amount of corrosion between the skin and core had resulted in a zero strength value, refer Figure 31. In another area, where flexure of the core and skin was identified, the reduction in tensile strength to 200psi had resulted from an unsuccessful injection repair, refer Figure 32. Injection repairs have previously been identified by ASI-SRS[7] as causing panel degradation through moisture ingress and the inability of the process to successfully repair disbonded skin to core and edge-member regions. Corrosion, particularly near perimeter regions of bonded panels, appears to be a process that can lead to significant degradation in panel strength. Core corrosion was identified in the controlled exposure of the Stab-Tip examined in 3.2, and clearly, is something that should be considered for panel inspection. The NDI examination also suggested panel degradation as a result of the Tap Hammer test. The tensile strength in this area was adequate and highlights the difficulties in applying this method to successfully identify panel degradation or damage.

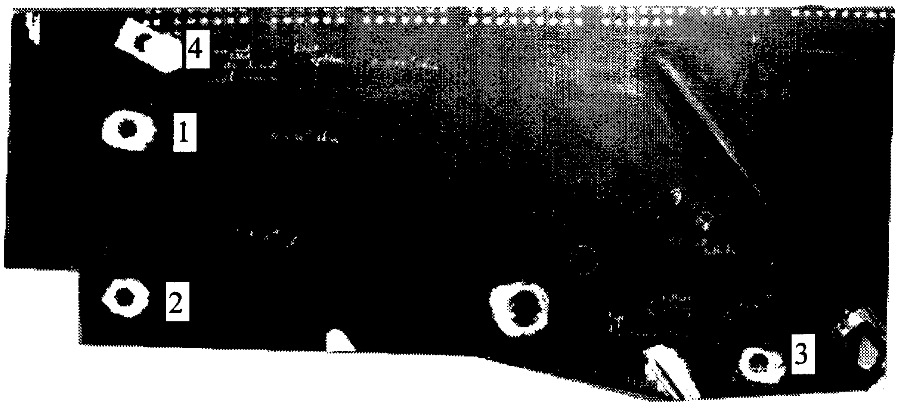

Figure 30 Positions of Elcometer tests taken from Stab-Tip Cap.

Table 3 Tensile strength of locations tested on Stab-Tip Cap, after NDI inspection.

Conditioning	**Position of Tensile Test**	**Pull-Off Tensile Strength (psi)**	**NDI Indication**	**Failure Mode**
As received from Amberley Airbase after component retired	1	915	no	Core fracture/cohesive
	2	800	Yes (Tap hammer disbond)	Core fracture
	3	203	Yes (Core flexure)	Fillet bond pull-out and void from ineffective injection repair
	4	0	Yes (corrosion)	Skin to adhesive disbond caused by corrosion

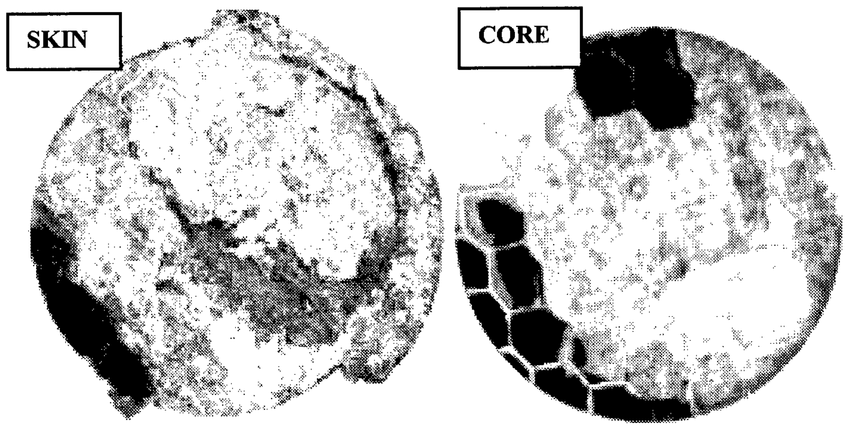

Figure 31 *Failure surface images from the tensile test taken in location 4, refer Table 3, of the Stab-Tip Cap where skin to adhesive corrosion has degraded the honeycomb panel strength.*

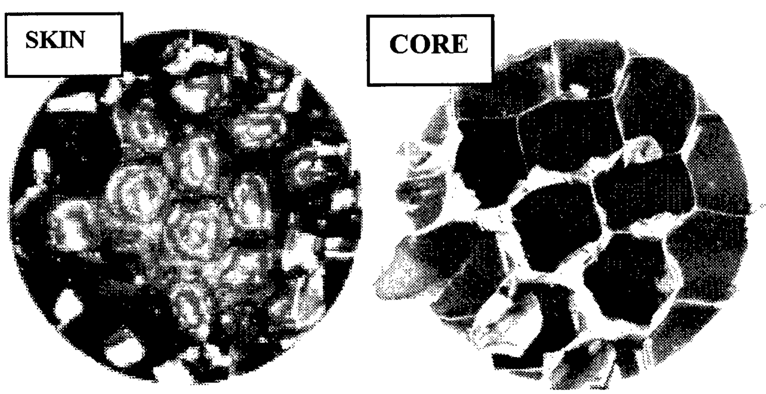

Figure 32 *Failure surface images from the tensile test taken in location 3, refer Table 3, of the Sta-Tip Cap, where an ineffective injection repair has degraded the honeycomb panel strength.*

4. Discussion/Conclusions

The data in Figure 1 indicates that direct exposure of the fillet bonds to moisture results in a significant reduction in the tensile strength of the honeycomb sandwich panel bonds and a significant increase in adhesion failure. In all cases the majority of the strength reduction and adhesion failure occurs within 30 days. This suggests that should moisture gain access to the bonded honeycomb panel on an aircraft that the reduction in panel tensile strength would be quite rapid. In the case of the AF131-2, the reduction in strength wasn't as marked as the other two systems examined and the percentage of adhesion failure was not as marked. AF-131-2 is used in higher temperature applications on the aircraft and subtle differences in epoxy resin chemistry may improve the adhesive bond formation process during panel fabrication. Generally, the bonded panel tensile strength appears to be inversely proportional to the percentage of adhesion failure and is directly related to moisture diffusing to the adhesive and honeycomb interfacial region and displacing the adhesive bonds from the aluminium honeycomb core surface.

The data in Figure 2 indicates that the change in peel strength for the different honeycomb-adhesive combinations is not as marked as in the tensile strength case. The adhesives tested, particularly the AF-130-2 and AF131-2 adhesives, are brittle and the lack of fracture toughness is shown by the low peel strength values. The newer JD-Lincoln adhesive, shows higher peel resistance, but degrades rapidly in strength once exposed to the moist environment. Both the AF130-2 and JD Lincoln samples indicated that peel strength reduction was associated with a significant increase in adhesion failure either at the skin to adhesive interface or the honeycomb core to adhesive interface. The AF131-2, in contrast, showed a percentage of cohesive fracture of the fillet bond adhesive even after extended exposure, without significant changes in peel strength being observed. The recorded failure modes will provide an important reference for the type of fracture surfaces that will indicate adhesive bond degradation in bonded panels being inspected on the F-111 teardown article in Task Air 00/140.

The reduction in peel and tensile strength together with an increase in adhesion failure over a relatively short period of exposure to a humid environment indicates that the simple treatments used for the honeycomb fabrication are relatively poor in terms of producing durable adhesive bonds. Newer honeycomb material treated with modern surface pre-treatment procedures and bonded with current adhesive systems have shown markedly improved durability performance in contrast to the systems examined in this report [2].

Despite the poor performance of the fabricated honeycomb samples tested in section 3.1, the Stab-Tip, generally indicated that the condition of the bonded structure was not significantly degraded. After 13 months of immersion in ionised 50^{0}C water, the majority of the bonded panel indicated no change in panel strength, despite a large

number of holes in the panel being present. In one location moisture ingress into the core had led to corrosion and consequent failure during tensile loading. However, in the majority of cases a mixture of cohesive fillet bond fracture and core fracture was observed. This mode is typically observed for the lighter gauge core material used to fabricate the Stab-Tip panel.

The Stab-Tip Cap indicated an area where significant strength reduction was caused by corrosion between the fillet adhesive and aluminium skin. This example of corrosion failure suggests that regions susceptible to moisture ingress on bonded panels should be considered carefully during routine aircraft maintenance and inspection. NDI of the Stab-Tip Cap also suggested that the Tap-Hammer test is potentially difficult to apply in a consistent and reliable manner to identify disbonded panel regions. The area identified by the Tap-Hammer test indicated Tensile strength values were normal. The Stab-Tip Cap inspection also highlighted the deficiency in the use of injection repairs. The reduction in tensile strength and observation of the failure mode suggested that the injected potting compound had not adequately wetted the core and skin, leading to a weak adhesive bond. The low strength value recorded also suggested that strength of the potting compound was low, as indicated by regions where the potting compound had fractured cohesively.

The evidence from the tensile and peel strength measurements of the fabricated panels and retired service panels suggests that the effect of moisture on two sided panels is markedly slower than for the single sided panels. The Stab-Tip panel did not show significant evidence of bond degradation in regions that were only millimetres away from ionised, 50^0C water after 13 months of exposure. In contrast, the samples tested in section 3.1 showed rapid degradation after a few weeks. The initial stages of fillet bond pull-out were identified in some of the conditioned Stab-Tip samples, although there was no obvious effect on the tensile strength in these regions. This highlights the need to prevent moisture ingress into panels in regions such as edgemembers and fastener holes. The difference in degradation rates between the Stab-Tip panel and fabricated samples may also indicate a difference in durability between the panels that were manufactured during the original aircraft construction and the panels that were rebuilt or refurbished by the USAF using the materials used in section 3.1. Despite the lower conditioning temperature used for the Stab-Tip, the samples were immersed in ionised water and areas tested after 13 months of conditioning were only millimetres away from a direct water source. However, there was very little evidence of adhesion failure and in the only area where moisture appeared to have diffused into the honeycomb core, failure resulted from corrosion of the core, as opposed to an adhesion failure mechanism.

5. Recommendations

On the basis of the conclusions drawn from the investigations detailed in the current report the following recommendations can be made:

1) In the case of honeycomb sandwich panels that have been rebuilt or repaired using the CAE pre-treatment and either AF-130-2, AF131-2 or JD Lincoln adhesive and Alcore Duracore or Untreated honeycomb, particular attention should be paid to inspecting regions of the panels on aircraft structure that are susceptible to moisture exposure such as edgemembers and fastener holes.

2) Due to the poor durability of honeycomb sandwich panels that have been rebuilt or repaired using either AF-130-2, AF131-2 or JD Lincoln adhesive and Alcore Duracore or Untreated honeycomb, special attention should be given to ensuring perimeters of panels are carefully sealed to prevent any moisture ingress.

3) During inspection and maintenance, regions of panels containing old or existing injection repairs should be carefully inspected for potential disbonds and corrosion.

4) The RAAF should request advice on the feasibility of having critical panels rebuilt using modern honeycomb and adhesive materials and surface pre-treatment processes, given the potential shortcomings of USAF rebuilt panels.

6. References

1. A. N. Rider, "*F-111 Bonded Panel Repair Status*", DSTO-TR-0803, DSTO-AMRL, Melbourne, April, 1999.
2. A. N. Rider, "The Durability of Metal-Honeycomb Sandwich Structure Exposed to High Humidity Conditions", DSTO-Technical Report, 2001
3. Marceau, JA. In: Thrall EW, Shannon RW (editors), Adhesive Bonding of Aluminium Alloys , Chap. 4. New York: Marcell-Dekker, 1985.
4. ASTM D4541-95, "*Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*", 1995 Annual Book of ASTM Standards, Section 6, Volume 6.01, ASTM, Pennsylvania, 1995.
5. ASTM D1781-98, "*Standard Test Method for Climbing Drum Peel Test for Adhesives*", 1998 Annual Book of ASTM Standards, Section 15, Volume 15.06, pp. 106-109, ASTM, Pennsylvania, 1998.
6. AED-FFDA NDT Inspection report 06/99
7. M. J. Davis, D. A. Bond, "*The Importance of Failure Mode Identification in Adhesive Bonded Aircraft Structures and Repairs*", presented at the International Conference on Composite Materials 12, Paris, July 5-9, 1999.

DISTRIBUTION LIST

Degradation of Peel and Tensile Strength of Bonded Panels
Exposed to High Humidity

A.N.Rider

AUSTRALIA

DEFENCE ORGANISATION

Task Sponsor

ASI4A
DGTA

S&T Program

Chief Defence Scientist
FAS Science Policy
AS Science Corporate Management
Director General Science Policy Development
} shared copy

Counsellor Defence Science, London (Doc Data Sheet)
Counsellor Defence Science, Washington (Doc Data Sheet)
Scientific Adviser to MRDC Thailand (Doc Data Sheet)
Scientific Adviser Joint (Doc Data Sheet)
Navy Scientific Adviser (Doc Data Sheet and distribution list only)
Scientific Adviser - Army (Doc Data Sheet and distribution list only)
Air Force Scientific Adviser
Director Trials (Doc Data Sheet and distribution list only)

Aeronautical and Maritime Research Laboratory

Director
Chief Airframes and Engines Division
Alan Baker
Andrew Rider
Richard Bartholomuesz

DSTO Library and Archives

Library Fishermans Bend (Doc Data Sheet)
Library Maribyrnong (Doc Data Sheet)
Library Edinburgh
Australian Archives
Library, MOD, Pyrmont (Doc Data sheet only)
US Defense Technical Information Center, 2 copies
UK Defence Research Information Centre, 2 copies
Canada Defence Scientific Information Service, 1 copy
NZ Defence Information Centre, 1 copy
National Library of Australia, 1 copy

Capability Systems Staff

Director General Maritime Development (Doc Data Sheet only)
Director General Aerospace Development (Doc Data Sheet only)

Knowledge Staff

Director General Command, Control, Communications and Computers (DGC4) (Doc Data Sheet only)

Army

ABCA National Standardisation Officer (4 copies)
Land Warfare Development Sector
Tobruk Barracks
PUCKAPUNYAL VIC 3662
SO (Science), Deployable Joint Force Headquarters (DJFHQ) (L), MILPO Gallipoli Barracks, Enoggera QLD 4052 (Doc Data Sheet only)
NPOC QWG Engineer NBCD Combat Development Wing, Tobruk Barracks, Puckapunyal, 3662 (Doc Data Sheet relating to NBCD matters only)

Air Force

ASI-SRS

Intelligence Program

DGSTA Defence Intelligence Organisation
Manager, Information Centre, Defence Intelligence Organisation

Corporate Support Program

Library Manager, DLS-Canberra(Doc Data Sheet only)

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy
Library
Head of Aerospace and Mechanical Engineering
Serials Section (M list), Deakin University Library, Geelong, 3217
Hargrave Library, Monash University (Doc Data Sheet only)
Librarian, Flinders University(Doc Data Sheet only)

OTHER ORGANISATIONS

NASA (Canberra)
AusInfo

OUTSIDE AUSTRALIA

ABSTRACTING AND INFORMATION ORGANISATIONS

Library, Chemical Abstracts Reference Service
Engineering Societies Library, US
Materials Information, Cambridge Scientific Abstracts, US
Documents Librarian, The Center for Research Libraries, US

INFORMATION EXCHANGE AGREEMENT PARTNERS

Acquisitions Unit, Science Reference and Information Service, UK

Library - Exchange Desk, National Institute of Standards and Technology, US

National Aerospace Laboratory, Japan (Doc Data Sheet only)

National Aerospace Laboratory, Netherlands(Doc Data Sheet only)

SPARES (copies)

Total number of copies: **40**

Page classification: UNCLASSIFIED

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA	1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Degradation of Peel and Tensile Strength of Bonded Panels Exposed to High Humidity	Document (U) Title (U) Abstract (U)
4. AUTHOR(S)	5. CORPORATE AUTHOR
Andrew N. Rider	Aeronautical and Maritime Research Laboratory 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-1272	AR-012-149	Technical Report	November 2001

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
M1/9/975	AIR 98/186	DGTA	24	7

13. URL on the World Wide	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-TR-1272.pdf	Chief, Airframes and Engines Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

Adhesive Bonding, Honeycomb, Bonded Panels, Durability

19. ABSTRACT

Bonded sandwich panel structural integrity is an important component in the successful maintenance and continued operation of RAAF F-111 aircraft through to the planned withdrawal date of 2020. F-111 airframe stiffness and strength is dependent on the integrity of bonded sandwich panel structure. Currently, limited knowledge exists as to the effect of environmental exposure on the mechanical integrity of bonded sandwich panels. The work presented in this report summarises honeycomb studies undertaken in AIR task 98/186 that were designed to examine the influence that environmental exposure would have on the peel and tensile strength of bonded sandwich honeycomb panels constructed from either original materials or materials used in the refurbishment of damaged panels. The results indicate that the materials and processes used by the United States Airforce in repair and rebuild programs are susceptible to mechanical degradation as a result of exposure to high humidity conditions. However, the panels constructed during the original aircraft manufacturing indicate better resistance to the effects of environmental exposure.

Page classification: UNCLASSIFIED